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PERMAFROST - WHY THE MYSTERY

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Thomson.

In the mythology surrounding the Alaskan Northland which grew out of the great Klondike rush, frozen ground, particularly permanently frozen ground developed properties which are nearly as terrible as those ascribed to the Alaskan mosquito and "no-seeum".

Since that time, over 70 years, many structures have been constructed on frozen ground, some with less than desirable results and some of these in recent years.

That a mystery remains is not due to a lack of research and documented experience of the highest caliber entering the body of engineering literature from many cold regions----rather I feel the mystery remains in part due to the lack of extensive and diversified construction in the Arctic.

This is not to discount the military, communications, public and recently petroleum construction, rather to note that in quantity of structures it possibly amounts to little more than the construction of Anchorage which probably could be dropped into a developed area similar to Los Angeles with scarcely a ripple.

In no manner should the engineer treat frozen soil, permafrost or seasonal frost lightly----it is a merciless adversary if not treated carefully and correctly.

Information of the highest quality does exist from the economics of thawing for mining purposes to the thermo-physical properties of the soil ice matrix.

In our limited time, we shall only scratch the tip of this pyramid of knowledge and then, I trust, primarily with respect to some of the most prosaic and sometimes over looked aspects of the problem which are of merit where time and funding requires the briefest of engineering study for a small remote project.

1. The most important element to the review is a definition of permafrost.

Permafrost is permanently frozen soil----keep it that way and you will usually have solved your total foundation problem.

2. The water portion of the soil mixture seldom is fully frozen----the percentage of the pore water being frozen is dependent on temperature, impurities (salts) and pore size.

The physical characteristics related to strength and subsidence properties may be significantly affected by the percentage of frozen pore water.

3. The pore water may or may not be at a thermo state where a slight increase in the quantity of heat results in thawing. If near thawing, a critical problem may result related to the structure's foundation that may require positive continuous removal of heat from the soil mass. Also, the soil in the process of exploration may appear thawed embarrassing the engineer at a later date.

4. The depth of permafrost depends on the heat cycle and the soil type(s), moisture content, void ratio, minerals, etc., all of which boil down to a handy dandy perameter "thermo conductivity".

A thermo gradient is set up in the soil mass with heat flow being toward the cold boundary; the surface during the winter and some point below the surface during the summer. The lower boundary being controlled by the earth's natural heat source which increases in temperature roughly at about 1.8 degrees F/100' of depth.

Depending on exposure conditions, the depth of permanently frozen ground can theoretically range from 0+' to about 2,000'.

5. Permafrost, while common to interior Alaska, is not always present and while not common to some of the Coastal areas is at times encountered in areas as temperate as Anchorage.

6. Permafrost comes in three general types; aggrading, static and degrading. The differences are subtle and may be upset generally toward degrading by changes in cover and other improvements. In general, it is prudent to assume degradation is the problem. However,

aggrading permafrost has embarrassed some projects in the past.

7. What to look for:

(A) Soil type----is it fine, mixed or coarse grained.

(B) Ice lenses or crystals----are they massive, do they fill the voids.

(C) Density of soil----is it loose, medium or dense. (If dense, probably little problem in thawing except for cyclic seasonal frost heave.)

(D) Moisture content----is the soil saturated, is the moisture content such that the soil is suspected of being loose.

(E) Temperature conditions----statistically is the prevailing temperature such that permafrost in its natural condition of cover should be stable, increasing or decreasing.

(F) Cover----does natural insulation exist, what is the surface water situation; will reflection and shade present heat gain or loss of significance.

(G) Effect of planned construction----will a general heat gain result to the developed area, to point of specific and critical interest.

8. How to look.

Permafrost is somewhat difficult to explore. It is usually difficult to drill or excavate rapidly without relatively robust equipment or thawing. If thawed, the soil mass often is so severely altered that the soil samples may be partially to completely misleading.

We have found that conventional drilling techniques with appropriate bits can usually advance a dry hole; that refrigerated liquids or gases on occasion are useful for tool and sampler cooling.— that much information of significance may be obtained by a driven split spoon (Standard Penetrometer or larger). The information including soil type, layering, presence of ice crystals - lenses, moisture content and to a very minor extent, the resistance to driving is of value. (If very low and the soil is a relatively dry and non-cohesive a loose structure is indicated; if fine grained, with a reasonably high moisture content subsidence and a near thaw state may be suspected).

Undisturbed sampling is difficult and requires attention to tool and sampler cooling, protection of samples at the expected ground temperature during retrieval, transport and subsequent testing— it is a costly time consuming procedure and should generally be entered into with caution and careful preplanning. Changes in moisture content of the sample due to warming or cooling are a critical problem in some instances.

9. Information on Hand — Situations to analize.

With respect to the frozen soil, two states exist which may be considered to differ from thawed soil mechanics.

(A) The effect of thawing — loss of bearing, subsidence.

(B) The effect of overloading a frozen soil mass----plastic properties.

Overloading with plastic flow of the ice portion of the system is a special problem—one which can cause grief to pile systems —its effect is analogous to thawing.

Thawing of the permafrost is the common general danger and one which may result in cyclic freeze thawing with the consequent problem of frost heave.

Should the soil be dense though frozen, subsequent thawing may result in little total or differential settlement. However, it may all occur after completion of construction with the result that tight doors, cracked slabs and drywalls suddenly appear, causing distress to the occupants, though usually little or no problem to the structural frame.—This situation is sometimes encountered in seasonal frost areas and is probably the basis for the standard caution against founding on frozen ground!

Should the relative density approach the loose state, additional subsidence may occur and may result in structural distress. Such subsidence is usually time dependent, being a function of the rate of thaw.

Should separation of the particles, due to the presence of ice crystals or layers exist, subsidence becomes greater though still time dependent. The anology is somewhat similar to settlement by consolidation of clay layers, with the amount often being quite large.

Remarkably large differential settlements have been observed, which do not necessarily cause structural failure of the frame and in some instances are not particularly noticeable except by crack patterns in the brittle components; such as P.C. concrete and drywalls. However, sticking doors, loud pops in the structure and propogating cracks are unnerving to the occupants and should be avoided.

In general, then thawing will result in subsidence and more important in differential subsidence. Only in the case of a very permeable soil would pre-thawing appear to be economic for the normal time allowed for construction.

Thus, after determining that subsidence is critical to the works, the corrective measure is generally preservation of the frozen soil below and about the points of bearing.

This may be accomplished by active or passive means.

The active case is mechanical or natural refrigeration cycles and may include a grid of tubes in an embankment or pile-piers below the structure. Two patented systems which rely on the atmosphere for heat exchange are the "Long Thermopile" and the "Dyna Pile", both developed in Alaska and both of which have proceeded far enough in R & D and field application to be considered as foundation components. In essence, these

systems make the soil as cold or colder than it existed in nature with the result that a bulb or layer of cemented (with ice) material is developed which results in a stable strong foundation. The danger is failure of the refrigeration system with resultant thawing and loss of the cementing action resulting in differential movement. The anology would be marine borers attacking piling.

Variations of the active refrigeration systems are heat sinks. These may be surcharges, which are purposefully frozen during the winter with encouragement of freezing by means of air distribution systems throughout the soil mass constructed of thin wall metal pipe ("wrinkled tin" culvert).

In some cases, a perched water table may be frozen in the winter and allowed to absorb heat through the summer, thereby protecting compressible soils at depth.

Much more rigorous approaches to the problem of encouraging the permafrost to remain stable exist in the literature.

The passive approaches generally rely on insulation to retard thawing of permafrost. Often they have included retention of the natural overburden and/or an increase in organic cover prior to placement of embankment. This approach has merit for pioneer roads and temporary structures where minimum cost is vital.

The quality of insulation may be increased and may include soil or patented materials, such as expanded polyurathene.

The balance between thawing or conversely increased freezing can become sticky in such situations, and the engineer in such instances should revert to fundamentals, specifically control of ground water in that zone which may become permanently or cyclic frozen—else he may not have just a problem of sinking into the sunset on his hands, rather a problem of rising and falling with the seasons. That is; watch out for frost heave!

One of the oldest and most successful passive systems is the piling ---ventilated crawl space method--this is also the most abused of all systems!

Piling, in such instances, should (in the writer's opinion) be assummed to be deep piers. A determination should be made as to whether they are founded in a soil zone free of ice lenses and, of course, well below the expected thaw zone.

From that point on and dependent on the quality and type of data adhesion, etc., may be of sufficient significance to be economic to the foundation design. However, let us assume we know very little about the site, other than the soils are such that we wish to keep them frozen---and we expect subsidence if they thaw, and the structural system requires sufficient points of support to result in reasonably light pile loads. Then our interest in adhesion is in the nature of insurance---if we can keep the soil about the pile frozen, it follows that below it will be frozen, and settlement should be nill. We have a further interest at this point in adhesion---We are expecting the worst---cyclic surface freeze thawing with frost heave. Hence we must anchor the pile-pier down. (To the writer these considerations seem to always result in a 20' to 30' wood pile penetration even after using the various heat flow charts available from our friends at the U. of A.)---and taking care to insure freeze back about the pile-pier, positive surface drainage away from the piles and adequate ventilation under the structure to provide winter freezing and disposal of heat generated by the structure and its utilities.

Now, there is a problem with this system --- the people who occupy the structure. They often get cold feet because some one did not adequately insulate the floors and walls or provide attention to vapor and wind barriers---so they skirt the building---thus 30' piles look good for structures. When rationalizing such an opinion where calculations show 5', 10', or 15' should do the job, one only has to recollect the wonderous deflection of a structure founded on 10' piles when a hot water line sprung a leak which was not detected for several weeks--it went up and it came down!

The foregoing describes wood piles which provide fair insulation in themselves. Steel and concrete may be used. However, the designer in such cases should then be more careful of heat flow through the more conductive material.

Of prime importance to the small isolated job in an appreciation of the constructors difficulties and a more than average effort to remedy the effects of differential movement by design. The separation of structural components to allow elements of the structure to move differentially is often possible and results in little or no cost penalty in construction, with minor maintenance costs should movement actually occur.

An intriging class of structure—is the failure structure. Warehouses, garages, possibly hangars may at times fall into this group. Here the challenge is to the engineer's communicative skills—can he insure that the owner understands that slabs etc., may and probably will move to the extent that remedial work must be programed and accomplished; and in this, will the owner be so agreeable when such an occurance develops at least to the degree requiring correction 3 to 5 years from now.

In one such case, due to numerous time and cost constraints, the structure's shell was pile supported with adjusting units built into the pile caps and the floor being a winter placed gravel pad —in the cold, with a possible future concrete slab. The slab being broken into 10' squares to allow movement. The plan being future replacement and/or raising of the slab and periodic adjustment of the pile cap elevations should a pile or pile groups move. The test of the engineer's communicative skill is expected in 1971 or 1972 in this instance.

Seriously, an engineer when considering a structure on permafrost, should at the outset consider the effect of differential movement to the purpose of the structure and the consequences of remedial action as opposed to fail safe initial construction. This parameter complicates the economic phases of the design study and will expose the designers ego to bruising should the structure require the planned remedial procedure during its service life—as a few of us are comfortable when a structure does move and become bent.

MISCELLANEOUS

When considering slab on grade with conventional footings—be careful: we have seen such structures designed and constructed in good faith deform beyond satisfactory design tolerances. Remedial action is usually very difficult and costly.

When considering passive frost protection systems---face up to the cost of placing piling as deep as 30' or put adjusting jacks on their tops or provide auxillary refrigeration.

Help the contractor in this process a bit more than you would in temperate areas. Define methods which will advance his piles into the ground satisfactorily. In two instances, we recollect, the contractors were badly bruised by use of equipment which could not accomplish, with resultant problems in each succeeding step of construction caused by economic hardship and loss of precious summer weather.

The sonic pile, "Bodine Driver", recently demonstrated by Raymond Concrete Pile may result in a breakthrough in both exploration and foundations. The rate of placement of conduit in the ground by this system is remarkable and the soils which it may penetrate appear to include some rather coarse grained materials. The description of soil samples obtained by this sytem does a soil mechanics heart good. Sixty feet of core in man sized lengths with no gaps or lost horizons. They may actually approach the goal of being undisturbed.

The monitoring of the soil's temperature is not particularly costly and often should be included in the exploration/construction program. Heat gain below or within permafrost is not unknown being caused by an anomoly filled with warm drainage water, also it is well to determine by monitoring the effect of the passive or active protection system elected for construction. Thermister are the simplest long term monitoring units; thermo couples are possibly the best, other systems exist which show a change in state of a temperature sensitive material.

In closure, I should like to note that all of the foregoing is elementary and intended only for those minor, remote, build it yesterday projects, which are the exceptions.

In those instances where time, funds and an indulgent client exist, the majority, I trust, of your work, elaborate and careful studies may be made which place numbers in the symbols of the various design equations resulting in those foundation systems which are nicely in tune with the completely known use of the structure and its physical environment during its 100 year design life--resulting in absolute economy of construction.

Of course, the actual case fall between these two extremes, thus, hopefully my quaint experiences observing and attempting remedial action on some not all that old structures may prove of aid as well as amusement.

And, as to the mystery—it exists, because frozen ground is completely merciless to the best of us.

It is a complicated engineering material---one which may be altered long after the design engineer has moved on to other things.

We will let some one else scare us all with massive ground ice, and defer questions of frozen soil dynamics to another time.

Thank You.

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